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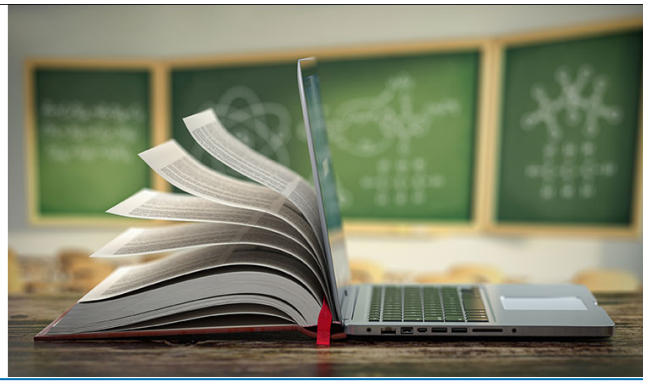

Aperiodic Schrodinger Crystals

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Abstract. In 1945, E. Schrödinger predicted the possibility of the existence of "aperiodic crystals," that is, more and more increasing crystalline aggregates, but without a simple lattice repetition mechanism. In the present work, such structures are experimentally prepared using selenium as an example. By thermal gradient treatment of the amorphous selenium film, we have obtained nano-thin spatial dissipative structures (SDS) of hexagonal selenium, the lattice of which undergoes non-uniform rotational curvature around, in the general case, three mutually perpendicular directions. The formation of these nano-thin SDS of hexagonal selenium occurs as a result of cooperative rotations of selenium macromolecules around, in general, three mutually perpendicular directions. Since nano-thin SDS after hardening in air have all the features of crystals each of the above nano-thin SDS of hexagonal selenium obtained at different annealing temperatures corresponds to the concept of "aperiodic crystals" Thus, "aperiodic crystals" were obtained experimentally, the possibility of the existence of which was predicted by E. Schrödinger.

1. Introduction

The concept of "aperiodic crystal", first introduced by Erwin Schrödinger in the book "What is life?" [1]. In the first chapter, on the pages of 12 and 13, E. Schrödinger defines an aperiodic crystal: "… periodic crystals are very interesting and complex objects.... However, compared to aperiodic crystals, they seem somewhat elementary and boring. The difference in structure here is the same as between ordinary wallpaper, on which the same pattern is repeated with the correct periodicity, and a masterpiece of embroidery, say, Raphaelev tapestry, which repeats the complex, consecutive and complete design pattern drawn by the great master...". Further, on the page 66 [1], E. Schrödinger gives an example of an aperiodic crystal: "… it is possible to imagine two different ways of building more and more associations. One is a relatively uniform way of repeating again and again the same structure in three directions.... The other way is to build a more and more increasing aggregate without a boring repetition mechanism. This is a case of an increasingly complex organic molecule, in which each atom, each group of atoms plays an individual role that is not quite equivalent to the role of other atoms and groups of atoms. We can definitely call this formation an aperiodic crystal...".

On page 82 [1], E. Schrödinger points to the mechanisms for the formation of ordered structures: "It turns out that there are two different "mechanisms" that can produce ordered phenomena: a

statistical mechanism that creates “order from disorder”,” and a new mechanism that produces “order from order”.

Thus, on the one hand, Schrödinger points to the possibility of the existence of “aperiodic crystals” –... “aggregates without a boring repetition mechanism,” and, on the other hand, determines the mechanism for their formation –... “a new mechanism that produces “order from order”.”

How right was E. Schrödinger, pointing to the possibility of the existence of aperiodic crystals? To answer this question, consider nano-thin spatial dissipative structures (SDS) formed in amorphous films.

2. Results and discussion

It is known that in amorphous films of selenium, during their thermogradient processing, nano-thin spatial dissipative structures of hexagonal selenium are formed [2–6]. In the process of electron-microscopic studies, and the methods of transmission electron microscopy, electronography and bending extinction circuits present on electron-microscopic images of nano-thin SDS were investigating nano-thin SDS of hexagonal selenium, presented in figure 1 [2, 3, 7–17].

Nano-thin diamond-shaped SDS of hexagonal selenium (figure 1, a) are characterized by a system of bending extinction contours parallel to the short diagonal of rhombus [2, 3, 6, 7]. Microdifraction studies of nano-thin SDS of hexagonal selenium [7–10] and analysis of flexural extinction circuits on electron microscopic images of nano-thin SDS make it possible to conclude: nano-thin diamond-shaped SDS (figure 1, a), formed in an amorphous film with one-sided heating of the lower surface at T = 453 K, are in a non-equilibrium state – their lattice experiences non-uniform elastic rotational curvature around [001], coinciding in direction with the axis OZ (figure 2). The rotation of the lattice of nano-thin diamond-shaped SDS of hexagonal selenium (figure 1, a) around [001] reaches 18^0 [2, 3, 6].

Thus, indeed, the formation of nano-thin diamond-shaped SDS of hexagonal selenium (figure 1, a) occurs “…without a boring mechanism of repetition” [1], and as a result of cooperative progressive rotations of Se macromolecules around [001].

Nano-thin diamond-shaped SDS of hexagonal selenium formed in an amorphous film during its thermal gradient treatment at T = 423 K (figure 1, b), characterized by a linear fan-like system of bending extinction circuits on electron-microscopic images.

Microdifraction studies of nano-thin SDS of hexagonal selenium (figure 1, b) and analysis of the system of bending extinction circuits present on electron-microscopic images of nano-thin SDS make it possible to conclude: – their lattice experiences inhomogeneous elastic rotational curvature around two mutually perpendicular directions – around [001] and around the OX axis (figure 2) [2, 3, 6, 18, 19]. The rotation angles of the lattice of nano-thin diamond-shaped SDS of hexagonal selenium with a linear fan-shaped system of bending extinction circuits on electron-microscopic images reach: around [001] – 18°; about OX axis (figure 2) – 22°.

Formation of nano-thin diamond-shaped SDS of hexagonal selenium (figure 1, b) occurs as a result of cooperative rotations of selenium macromolecules around two mutually perpendicular directions.

Nano-thin STS of hexagonal selenium with curved gabitus are formed in an amorphous film during thermal gradient treatment by heating its lower surface at T = 413 K (figure 1, c).As a result of studies of nano-thin SDS conducted by electron-microscopic and microdifraction methods, it was found that nano-thin STS with curved gabitus (figure 1, c) are in a non-equilibrium state, their lattice experiences non-uniform elastic-plastic rotational curvature around three mutually perpendicular directions: around [001], around the OX axis and about OY axis (figure 2). The angles of rotation of the lattice of nano-thin SDS with the curved gabitus reach: around [001] – 25^0, around the axis OX – 32^0, around the axis OY- 35^0 (figure 2) [2, 5, 19].

Thus, the formation of nano-thin diamond-shaped SDS of hexagonal selenium (figure 1, c) also occurs... “without a boring mechanism of repetition” [1], and as a result of cooperative rotations of selenium macromolecules around three mutually perpendicular directions (figure 2) [2, 5, 19].

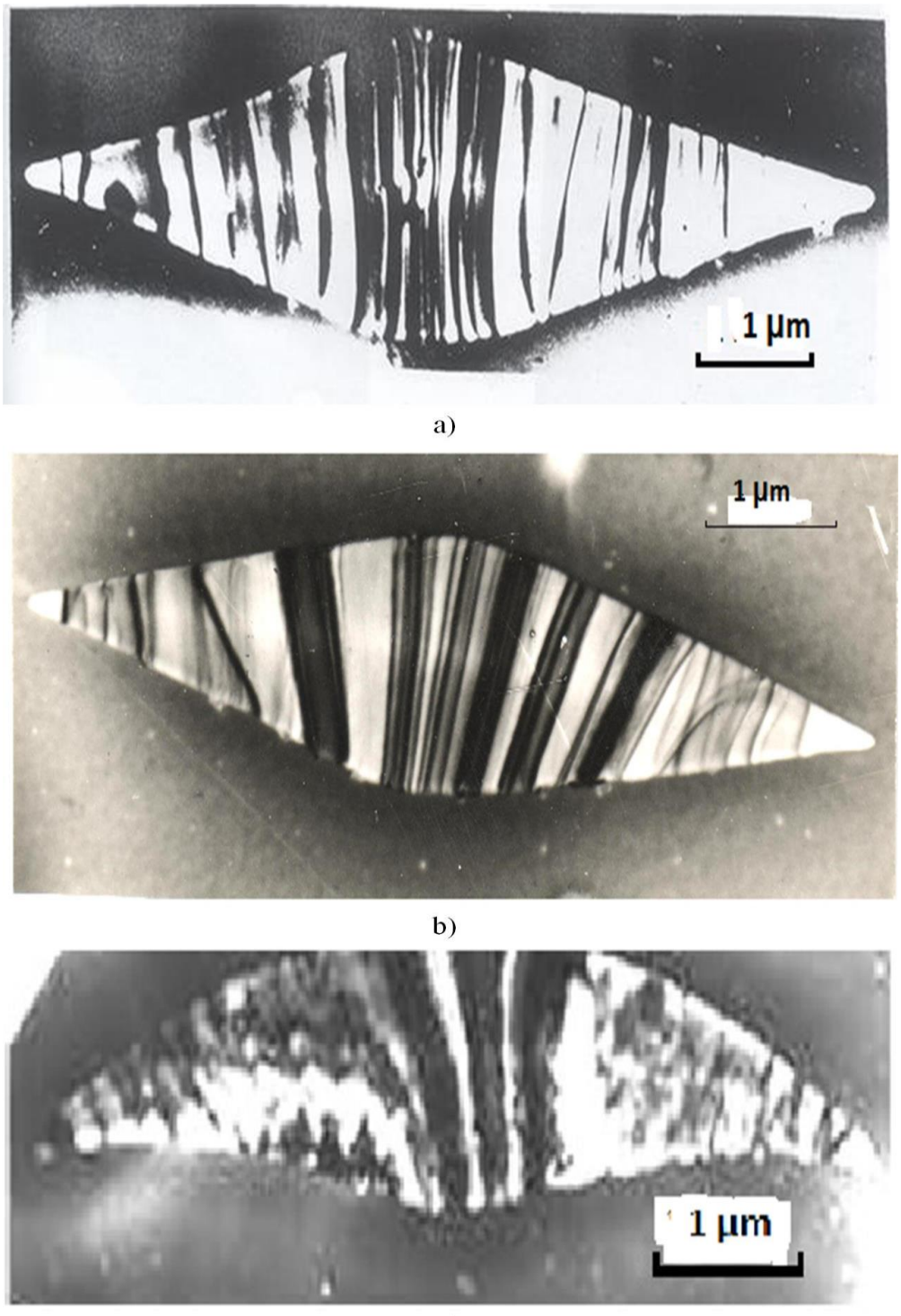

Figure 1. Electron microscopic image of nano-thin SDS hexagonal selenium, JEM-200CX JEOL Ltd, Japan: a) having a diamond-shaped gabitus and a system of bending extinction contours parallel to [001], coinciding with the short diagonal of the rhombus; b) having a diamond-shaped gabitus and a linear fan-shaped system of bending extinction contours; c) with curved habitus.

Since the structural units of the lattices of nano-thin diamond-shaped SDS of hexagonal Se with a parallel short diagonal of the rhombus are a system of bending extinction circuits on electron-microscopic images (figure 1, a); nano-thin diamond-shaped SDS of hexagonal Se with a linear fan-like system of bending extinction circuits on electron microscopic images (figure 1, b); nano-thin SDS of hexagonal Se with curved habitus and a non-linear system of bending circuits on electron microscopic images (figure 1, c) are selenium macromolecules [2, 5, 19–21]. Since it is clear that the rotation of the lattice of nano-thin SDS around one, two or three mutually perpendicular directions is the result of cooperative rotations of selenium macromolecules forming lattices of nano-thin SDS of hexagonal selenium (figure 1, a, figure 1, b, figure 1, c) [2, 5, 19–21], around one, two or three mutually perpendicular directions, respectively (figure 2).

The nano-thin SDS of hexagonal selenium shown in figure 1, a, figure 1, b, figure 1, c differ in complexity. The lattice of nano-thin diamond-shaped SDS (figure 1, a) experiences non-uniform elastic rotational curvature around [001], the lattice of nano-thin diamond-shaped SDS (figure 1, b) experiences non-uniform elastic rotational curvature around two mutually perpendicular directions [11], around – [001] and around the axis OX (figure 2); the lattice of nano-thin diamond-shaped SDS with curved gabitus (figure 1 c) experiences non-uniform elastic-plastic rotational curvature around three mutually perpendicular directions, around [001], around the OX axis and around the OY axis (figure 2).

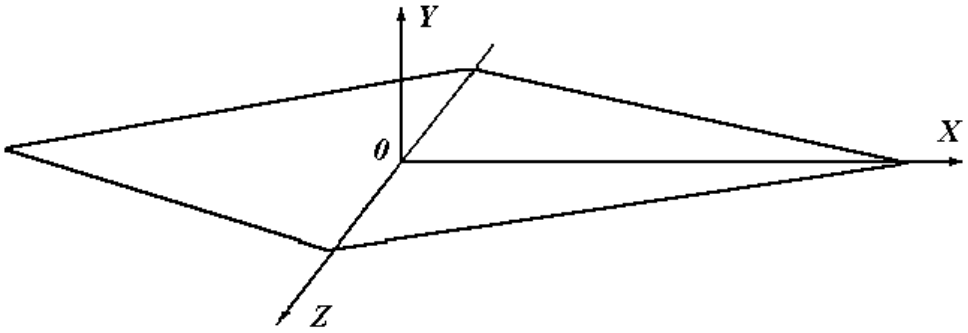

Figure 2. Coordinate system associated with nano-thin SDS of hexagonal selenium.

3. Conclusion

Since nano-thin SDS after hardening in air have all the features of crystals [2, 8, 10, 11], each of the above nano-thin SDS of hexagonal selenium (figure 1, a, figure 1, b, figure 1, c) corresponds to the concept of “aperiodic crystal” [1].

As a result, by thermal gradient treating an amorphous selenium film, nano-thin SDS of hexogonal selenium are obtained, the lattice of which experiences a non-uniform elastic or elastic-plastic rotational curvature around one, two or three mutually perpendicular directions. The formation of these nano-thin SDS of hexagonal selenium occurs as a result of cooperative rotations of selenium macromolecules around one, two or three mutually perpendicular directions. Thus, “aperiodic crystals” were obtained experimentally, the possibility of the existence of which was predicted by E. Schrödinger [1].

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